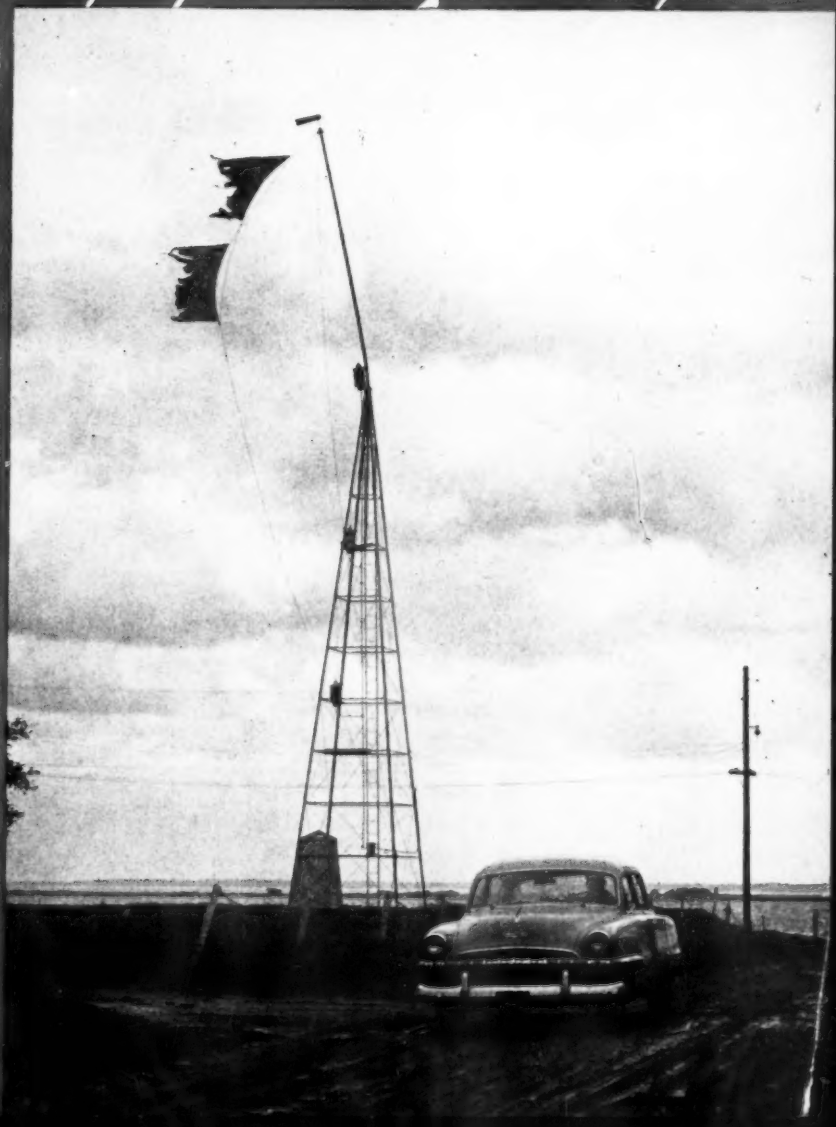
Weatherwise



Vol. 8, No. 4

AUGUST, 1955

"SOME PEOPLE ARE WEATHERWISE BUT MOST ARE OTHERWISE"—BENJAMIN FRANKLIN

WEATHERWISE

THE MAGAZINE ABOUT WEATHER

DAVID M. LUDLUM, *Editor* HENRY W. BULKLEY, *Associate Editor*

Early Weather Records

Christopher Columbus made the observation during his first week in the New World that it rains more or less every day in the Indies. Though the elements have continued to perform in this manner, no one has presented a coordinated historical account of the vicissitudes of the American weather scene. True, there are particular works on hurricanes, tornadoes, and floods; but the further one recedes from the printed records of the Federal services, commencing in 1870, the less satisfying the accounts become.

As a preliminary to writing a history of meteorological activity in North America prior to 1870, the editor of *Weatherwise* is conducting an inventory of early weather records. The present appears to be a propitious time to undertake this search as there has been a great amount of activity in recent years in collecting and cataloguing all types of archival material.

A request will soon be sent to all historical societies, scientific institutions, college and municipal libraries, for listings of all meteorological material in their possession. The Climatological Division of the Weather Bureau will conduct a canvass of all first-class stations. The material in the National Archives has already been carefully catalogued, as have the valuable Boston collections in the hands of the American Academy of Arts & Sciences and the Blue Hill Observatory.

In general, the following categories seem to yield the most fruitful material: 1) meteorological journals, 2) personal diaries, 3) contemporary newspaper accounts, 4) imprints on particular storms, 5) state and local histories, and 6) agricultural periodicals. A listing of the existing guides to meteorological records prior to 1870 will be found on page 97.

All readers of *Weatherwise* are cordially invited to assist in this undertaking by exploring their local sources of material. It is hoped that a complete inventory of early weather records can be published. Address all communications to:

WEATHERWISE, Box 216, Princeton, New Jersey

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Cover: Tattered hurricane warnings fly from a battered storm warning display tower on the Cape Fear River in North Carolina during Hurricane Hazel in October, 1954. Art Newton Studios photo.

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The Story of CRAZY DOCKETT —

(King of the Weather Men)

Born down in Texas, where the wind blows free,
The first thing he said was the word "Maybe."
Put out a forecast when he was only three,
And busted it flat, like you and me.
CRAZY, CRAZY DOCKETT, TYPICAL WEATHER MAN.

Went off to Cambridge and MIT,
Learned how to deal with vorticity.
Wrote an equation for ds/dt,
And gave it to Petterssen . . . all for free.
CRAZY, CRAZY DOCKETT, GENEROUS WEATHER MAN.

Joined with the Navy for quite a spell,
Went off to Europe and Japan as well.
Called out the weather for every shell,
And helped his mates give the enemy . . . well!
CRAZY, CRAZY DOCKETT, PRIDE OF THE USN.

Went into rainmaking for a year,
Caused it to rain when the skies were clear.
Seeded a cumulus with hops, we hear,
And down came a flood of lager beer.
CRAZY, CRAZY DOCKETT, HEAD OF THE WEATHER MEN.

Got himself a weather show on TV,
Showed everybody what the weather would be.
Reached such a height of popularity,
That they made him the head of NBC.
CRAZY, CRAZY DOCKETT, POPULAR WEATHER MAN.

Built a computer that was one of the best,
Took it to Las Vegas for atomic test.
Put in a nickel as sort of a jest,
And won the biggest pot ever seen in the West.
CRAZY, CRAZY DOCKETT, KING OF THE LAST FRONTIER.

This is his story, and now it's through.
We can't say it's false, and we can't say it's true.
It could have happened to anyone you knew,
And it could, and it might, just happen to you.
CRAZY, CRAZY DOCKETT, KING OF THE WEATHER MEN.

(By Toastmaster Gordon Weir at AMS Banquet, Los Angeles, June 1955)

The tornado model with the shallow pan of water at bottom and light source and blower at top. Photo by William Simmons.

A Tornado Model and the Fire Whirlwind

JAMES E. MILLER,
New York University

LIKE the lion a tornado is a dangerous thing in its natural habitat. It is also very hard to find if you are looking for one deliberately. And unlike the lion it cannot be captured and examined while confined in a cage.

Cowboy legend tells that Pecos Bill once rode a tornado like a bronco, but the legend does not tell if he found anything of scientific value. There are no more cowboys like Pecos Bill.

That being the case, how can we learn more about tornadoes? We may invent theoretical "models," in which the tornado is reduced to mathematical symbols on a piece of paper; or we can build physical models, in which the essential features are copied on a small scale and are kept under control. The trouble is that experts are not agreed on the essential features. So nobody knows for sure just how to arrange the symbols or put the scale model together.

At New York University last summer we were considering ways in which a tornado might be represented by a whirlpool in water. Everyone is familiar with the intense whirl formed when water runs down a drain. It resembles a tornado, whose most important feature seems to be a fast rotation about a center of very low pressure. But we were not satisfied with such a model. A tornado is formed by whirling air, not water, and water running down a drain is an upside-down tornado if it is a tornado at all.

We discovered that W. H. Dines had described a more realistic model in 1896. "I have never seen either a tornado or a waterspout," he admitted, "hence I cannot say that the cloud which I hope to show you is like the real phenomenon; but I think you will agree with me in believing that it bears a striking resemblance to the photographs and illustrations which most of us have seen."

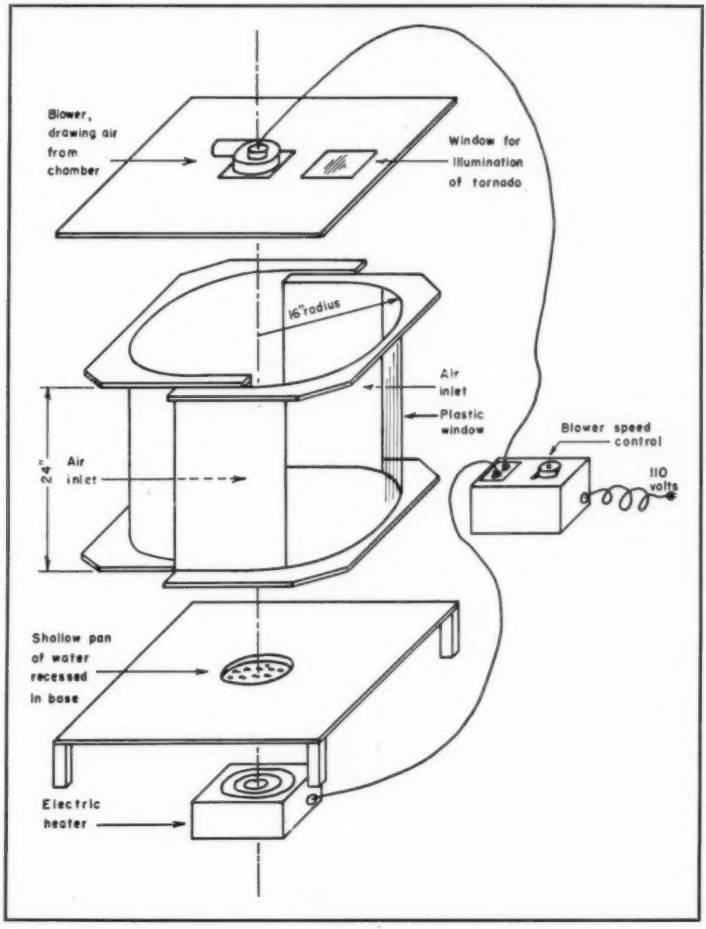
Convinced by Dines's description of the model, we constructed a duplicate, with some small changes that we thought would improve it. Our model, illustrated here, consists of a circular chamber with a pan of steaming water at the bottom and a blower drawing air out of the top. Fresh air enters the chamber through two vertical silts, and it is directed into the chamber in such a fashion that it must rotate about a vertical line in the center. As the blower draws the air toward the center and upward, the air rotates faster and faster. The centrifugal force of its rotation is opposed by a decrease of pressure toward the center of rotation.

Suppose we are ready now to produce a tornado. The water in the pan is heated until steam rises from it. The control on the air blower is turned up to start the circulation. For a few seconds nothing in particular happens. The steam cloud begins to rotate slowly. Then suddenly it forms a sharply defined vertical column an inch or two in diameter, with a hollow core. Wisps of steam at its edge are seen to spiral around and up the column at high speed.

The water in the pan directly beneath the column bulges up one-half to one inch, and droplets are torn off the surface and thrown violently outward.

Paul C. Kangieser of the Weather Bureau has experimented with a similar model. He suggests that each microscopic droplet in the steam cloud is acted on by two forces. One is the drag of the air spiralling toward the center. The other is the centrifugal force of the particle's rotation about the center. Within the hollow core the centrifugal force is stronger and the particles are all thrown outward. Outside the steam column the air drag is stronger and the particles are forced inward. The combined effect of these forces is to confine the steam particles in the shape of a hollow tube, like a mailing tube made of very thick cardboard.

But is this a true model? It looks like a tornado, to be sure. But we cannot call it a true model of a tornado unless it has the same causes and mechanics, and these are



An exploded view of the model showing components in detail.

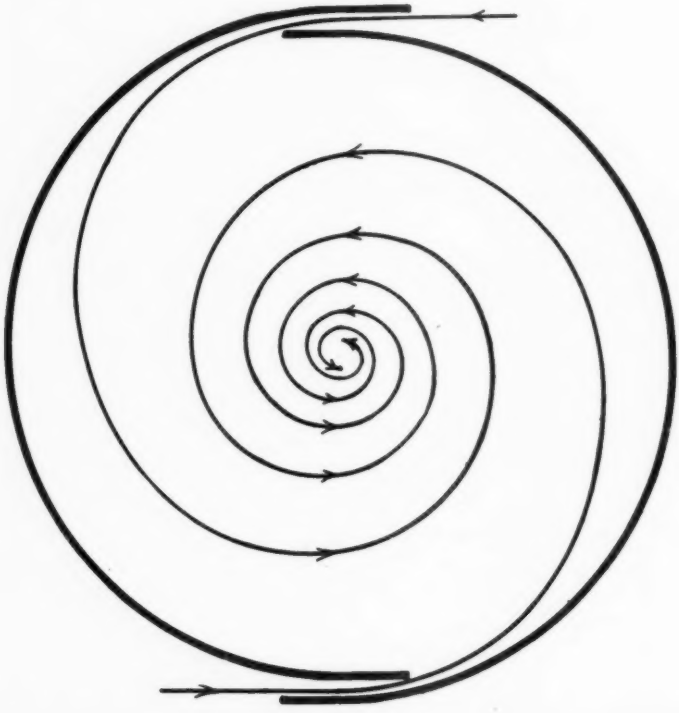
not certainly known. We may approach the problem through the back door. Having a model that looks right, we may use it to form a theory of tornadoes, and then hope to prove the theory by observations near (but not too near) a real tornado.

What are the causes of a tornado, according to the model? There are two: Somehow air must be drawn rapidly out of a region above the earth's surface; and the fresh air coming in at lower levels must have some absolute rotation in the very beginning. The rotation is easily explained. The rotation of the whole atmosphere with the earth about its axis is probably adequate. In addition, we find there is rotation of the air masses in areas where tornadoes form. The rapid withdrawal of air from a small region is not as easily explained. Perhaps it happens more often than we think. Perhaps here we have stumbled on an atmospheric phenomenon which is very important but very hard to observe directly.

A number of interesting experiments can be performed with the model. If a small balloon about an inch in diameter is dropped in the pan of water, the air circulation draws it toward the center, where it spins rapidly. After a little while it is picked up by the strong updraft in the center. Then, almost instantaneously, it is carried straight to the top of the chamber and thrown outward to the wall.

If the water in the pan is not heated, there is no visible column of steam to represent the tornado. But as long as the blower is running, the water rises in a small mound nearly an inch high, showing that there is a pressure decrease of a couple of millibars. If smoke is injected through a tube into the chamber, it spirals inward and upward. From these facts it is clear that the heat applied to the water is not an essential part of the model.

In another interesting experiment the blower is removed from the top and replaced by a can of Sterno "canned heat." The jelly in the can is lighted and a four-foot length of stovepipe, eight inches in diameter, is placed over it. The upward draft in the stovepipe draws air from the chamber. Since this draft is not as strong as the draft through a good



Streamlines of the air motion, viewed from above looking down into the circular chamber. If the air enters at a speed of 2 mph, it accelerates to about 32 mph by the time it is one inch from the center of rotation. The corresponding pressure drop is 1¼ mb, or ½ inch of water.

blower, the tornado is less violent but still recognizable.

A vivid description of a forest fire whirlwind appeared in an earlier issue of this magazine. "From our vantage point about 200 yards away," wrote Howard E. Graham of the Weather Bureau's Fire Weather Service, "it was evident that violent whirling surface winds existed near the fire over a diameter of some 100 to 200 feet. In the middle of this circulation was a dark tornado-like tube extending upward, whose top was obscured by drift smoke above approximately 1,000 feet. The winds in this tube were so extreme that a green Douglas fir tree, which at breast height was about 40 inches in diameter, was quickly twisted and broken off about 20 feet above the ground.

"Near the whirlwind the fire flames leaped several times higher than those in surrounding areas. A large treetop burst into flame like the flash of a powder keg when the whirl passed by. Within the tube, gases and debris were moving upward at a high velocity."

This phenomenon can be reproduced in the tornado model. The can of Sterno is set on the floor of the chamber in the center. The jelly is lighted and the blower at the top is turned on full speed. As soon as a strong circulation is started, the blower is removed from the top, because it is not needed to maintain the circulation and it would certainly be damaged if left in place.

The flame above the Sterno can is normally low, quiet, and so clear that it is almost invisible. As the circulation strengthens, the flame rises to a height of about eighteen inches. It becomes reddish and more intense, and begins to roar like a blow-torch. Then the experiment turns into a war of nerves. Shall we wait until the fire whirlwind has grown to maximum intensity, or will it set fire to the wooden top of the chamber? We have not yet continued the experiment to the point where this question could be answered.

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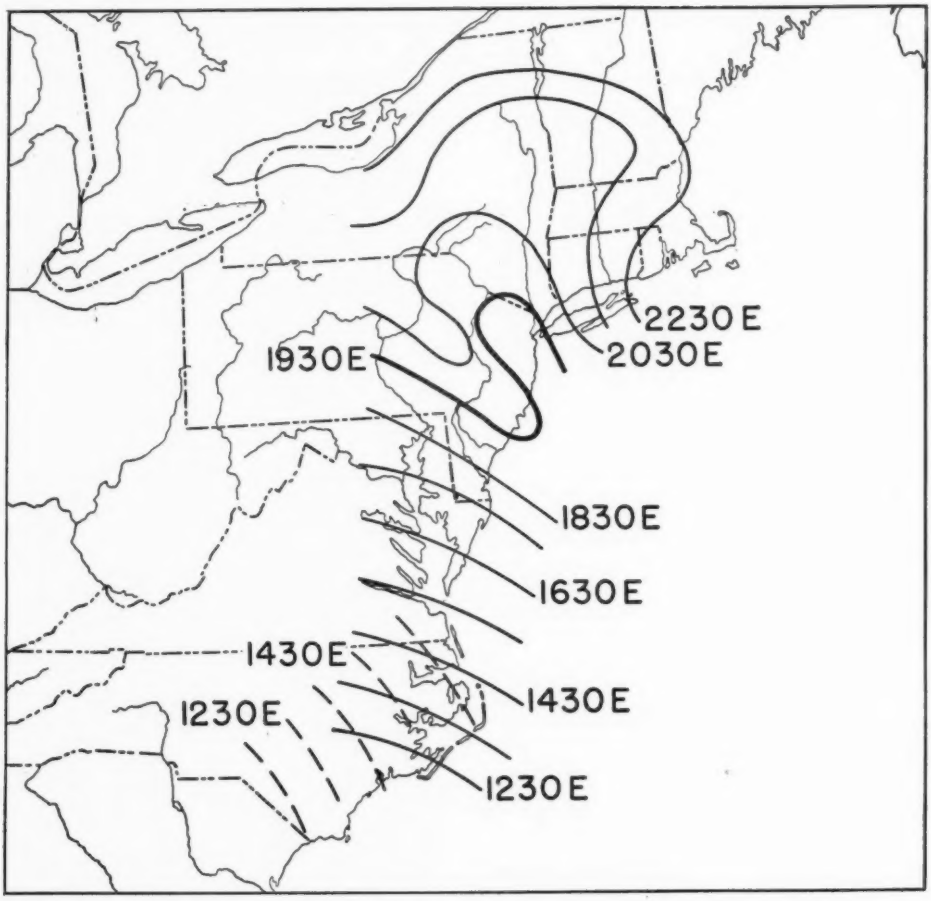
The fire whirlwind as shown by a time exposure of one second. Note the spiral path formed by a spark. Photo by William Simmons.

The Distribution of Peak Wind Gusts in Hurricane Hazel 1954

CONRAD P. MOOK, *USWB, Washington National Airport, Washington, D. C.*

AN important problem in the study of the structure of hurricanes and typhoons and in forecasting associated high winds concerns the location of the highest wind gusts relative to the moving center of the storm. A recent study by Mr. Lawrence Hughes, at the University of Chicago, of observations made by aircraft flying into typhoons in the



The solid lines represent isochrones or lines of equal time occurrence of peak gusts. The dashed lines over North Carolina indicate a second occurrence of peak gusts which later overtook the primary isochrone, giving the 1930 EST line a peculiar twist over New Jersey and eastern Pennsylvania.

Pacific at an altitude of 1,000 feet reveals the distribution of wind about the centers. His charts demonstrate that the highest winds, 90 knots or greater, are located in the right rear quadrant of the storm. Mr. Hughes reports these to be in agreement with the data published by the Rev. Charles E. Deppermann of the Philippine Weather Bureau in 1937 and by Dr. Isaac Cline of the U. S. Weather Bureau in 1926.

These earlier studies concentrated their attention upon data from land stations over or near which typhoons or hurricanes passed. It often happens that such storms quickly lose their intensity upon moving over land. In the case of Hurricane Hazel, which moved inland near the North and South Carolina border on 15 October 1954, we have an unusual instance of a hurricane maintaining its energy for a long distance over land. It was thus possible to observe the time of the peak gust or highest sustained winds over a vast land network of U. S. weather stations and to subject them to careful analysis.

In this study hourly maps of the storm were constructed showing the pressure and wind gust distribution beginning at 1130 EST. In addition to lines of equal pressure, lines of equal wind gust, called isotachs, were constructed. The area enclosed by the 50-knot isotach is shaded on the various hourly maps shown in figures 2–9. These charts show that destructive gusts of 50 knots or more occurred far in advance of the storm center. For example, in terms of the actual events, power failures due to falling trees occurred in the Washington, D. C. area long before noon of 15 October when the storm center was still in southern North Carolina.

Figure 10 shows the results of plotting the time of occurrence of the peak gust and constructing lines (isachrones) through points of equal time of peak gust occurrence. This procedure resulted in two such lines through North Carolina where two peaks were observed at some stations. As will be shown later, this phenomenon accounts for the peculiarly bent isochrone for 1930 EST.

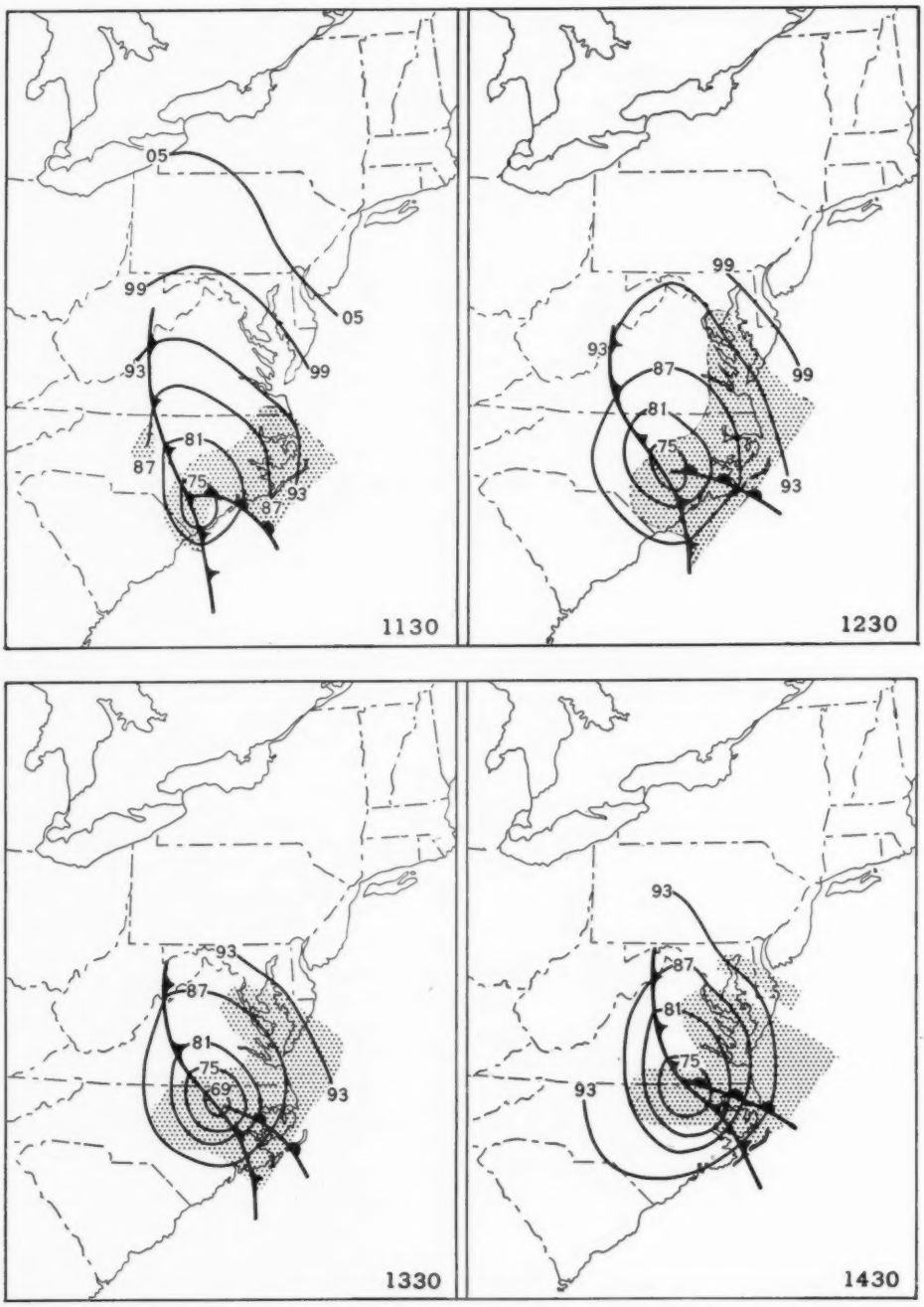
The passage of the line of peak gusts, which moved northward over eastern North Carolina and extended southeastward from the hurrican center, was accompanied by a slight wind shift usually from east-southeast to southeast and a four or five degree (F) dew point drop. This line was probably not a warm front, but might have been the convergence line described by Deppermann as separating the trade wind stream of air from that which he calls the "southwest monsoon" sector of the hurricane. In the figures, this line is shown as a warm front.

The line of peak gusts south of the hurricane center, which crossed North Carolina from west to east and whose westerly winds caused considerable damage, was accompanied by a wind shift to a more westerly quadrant and a subsequent drop in temperature and dew point such as attends the leading edge of a polar air mass. This line may be characterized as a cold front and later overtook the northward-moving convergence line in Delaware. Upon reaching New Jersey, the passage of the "occlusion" of the two lines was marked by a wind shift and a sudden termination of heavy rain, as well as being a line of peak gusts.

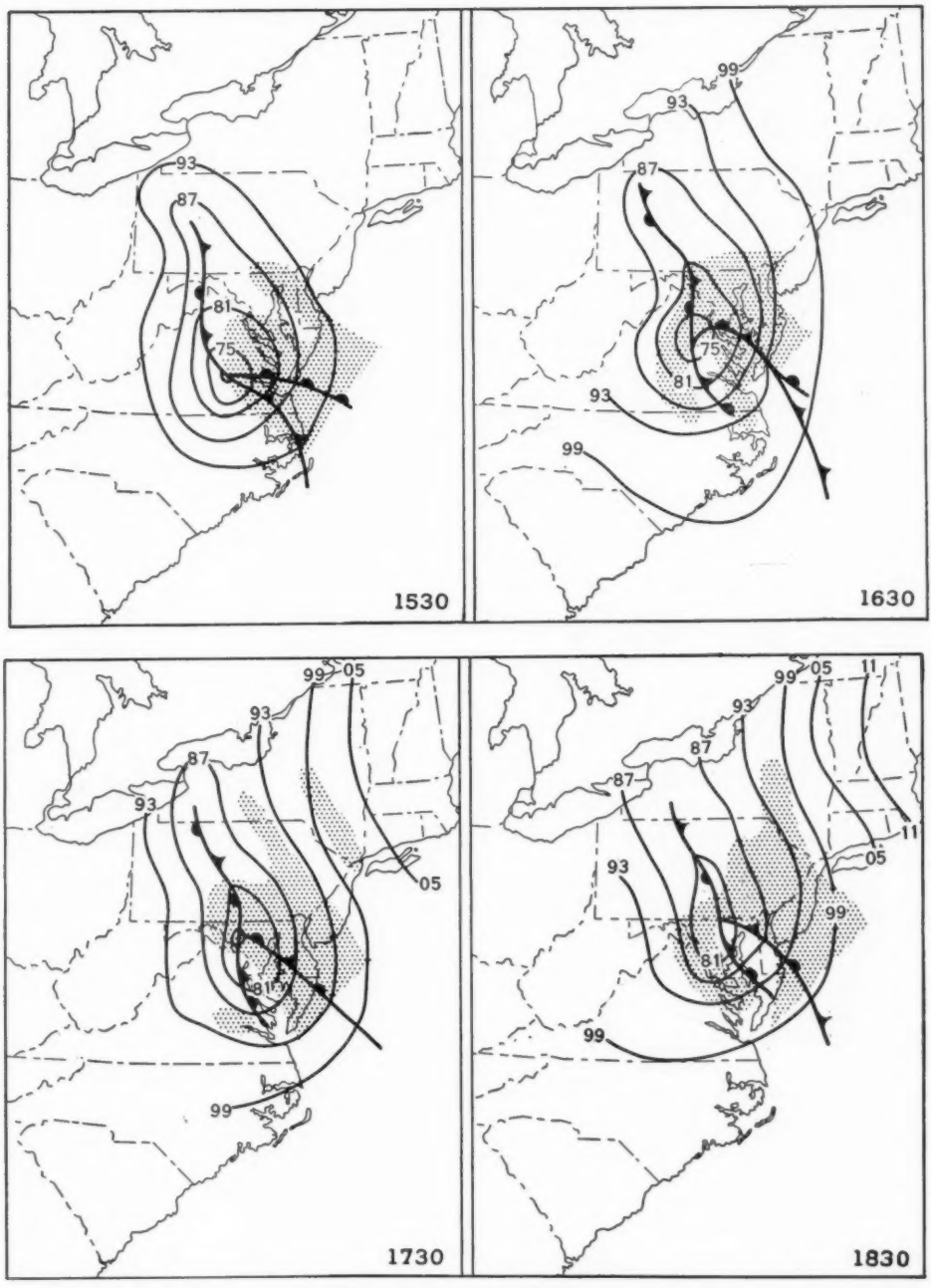
As the center of the hurricane moved northward over Virginia, a third line of peak gusts associated with a wind shift appeared to be developing as shown in figure 7. Actually, the peak gusts at many stations were associated with this line. While there was a localized peak gust line over Philadelphia and New York City, the gusts in the Philadelphia area associated with the bent back occlusion were the highest during the storm in that area. The sector ahead of this line experienced steady gales and hurricane winds from the south-southwest and dew points in the 60's, bearing considerable similarity to the southwest monsoon sector of Deppermann. With the passage of this line, the wind shifted further into the southwest or west, and temperature and dew point readings showed a steady drop.

The highest gusts of wind at inland stations such as Raleigh, North Carolina, and Washington, D. C., while coming at a time near the actual passage of the hurricane center, can be associated with wind shifts. East of the center, at Cherry Point and New Bern, North Carolina, one could identify the passage of the northward-moving convergence line and the cold front from the following data:

(Continued on following page)



Solid lines are isobars around the "tropical" center of Hazel from 1130 to 1430, 15 October 1954, as the hurricane moves northward across North Carolina. (For 75 read 975 mb, etc.) The apparent "fronts" are lines of equal wind gusts or isotachs. Areas with 50-knot isotachs are shaded.



Solid lines are isobars around the "becoming extra-tropical" center of Hazel from 1530 to 1830, 15 October 1954, as the hurricane moves from Virginia to Pennsylvania. (For 05 read 1005 mb, etc.) The great expansion of the peak wind gusts over 50-knots is shown by the shaded areas.

(*Continued on following page*)

CHERRY POINT, N. C.

Time (EST)	Dew point	Wind direction	Wind speed and gusts (knots)	
1130	75	ESE	25	54
1230	68	SSE	40	70
1330	67	SSW	35	74

(The "warm front" passed between 1130 and 1230, the cold front by 1330.)

NEW BERN, N. C.

Time (EST)	Dew point	Wind direction	Wind speed and gusts (knots)	
1130	72	SSE	35	66
1235	71	SSE	40	66
1335	75	SSW	40	66
1430	66	SSW	15	30

(The "warm front" passed New Bern shortly after 1230 and the cold front shortly before 1330.)

Next, one can trace the passage of the cold front at Rocky Mount, North Carolina, and the passage of the northward moving convergence line at Cape Hatteras.

ROCKY MOUNT, N. C.

Time (EST)	Dew point	Wind direction	Wind speed and gusts (knots)	
1235	73	ESE	24	52
1314		ESE	40	64
1335	73	ESE	43	81
1437	57	WSW	43	73

(Note cold front passage between 1335 and 1437.)

CAPE HATTERAS, N. C.

Time (EST)	Dew point	Wind direction	Wind speed and gusts (knots)	
1324		SSE	47	70
1424	69	S	40	58
1524	70	S	37	50

(Note passage of northward moving convergence line between 1324 and 1424.)

All three fronts at Chincoteague and Norfolk, Virginia, are seen in the following tables which illustrate the development of a further phenomenon, a plateau of high winds, rather than a peak.

The shift from SE to SSE at Chincoteague occurred between 1610 and 1630 as moderate rain ended. This was the northward moving convergence line. The first 80 knot gusts occurred with the shift of wind from SSE to SSW, as the cold front passed. The passage

CHINCOTEAGUE, VIRGINIA

Time (EST)	Dew point	Wind direction	Wind speed and gusts (knots)	
1528	73	SE	51	59
1550		SE	55	74
1610		SE	50	70
1630	69	SSE	53	69
1650		SSE	55	80
1710		SSW	53	72
1728	69	SSW	55	75
1750		SSW	55	80
1827	63	SSW	40	60
1850		WSW	32	52
1928	61	SW	28	

of the bent-back occlusion occurred between 1827E and 1850E with the shift in wind from SSW to WSW. A drop in dew point was noted thereafter. Note here particularly the persistent strong gusts which occurred between the time of the passage of the cold front and the occlusion.

NORFOLK, VIRGINIA

Time (EST)	Dew point	Wind direction	Wind speed and gusts (knots)	
1430	72	SSE	45	75
1500		SSE	60	87
1530	61	S	52	87
1611		S	52	85
1630	60	S	50	87
1715		SW	35	45
1730	62	SSW	30	45
1810		SW	31	45
1830	57	SW	28	40

The northward moving convergence line passed Norfolk between 1500 and 1530. The passage of the cold front occurred between 1630 and 1715. The bent-back occlusion passed between 1730 and 1810. For a considerable period from 1440 onward gusts of greater than 100 mph were observed occasionally at Norfolk.

In Professor Cline's book one also finds that many of the peak winds were associated with shifting winds; these may have been either frontal shifts or, what is even more likely, some other type of convergence lines.

More recently Dr. H. Arakawa of Japan has shown that the existence of mountainous seas in the right quadrant of a typhoon off Japan is associated with the high and shifting winds of a "warm front type" convergence line.

WEATHER BUREAU POSITIONS

The U. S. Weather Bureau has a need for Meteorologists, Meteorological Aids, and Electronic and Radar Technicians. New and augmented Weather Bureau public service programs will require trained Meteorologists for forecasting and research; Meteorological Aids for surface and radiosonde observing, and map plotting; Electronic and Radar Technicians for installation and maintenance of instrumental equipment. People who have been trained in the military services, now released, as well as by universities, colleges and technical schools, are encouraged to apply.

Jobs will be located throughout the United States and at a few overseas stations. Salaries will generally be at the GS-5 ($3670.00 per annum), GS-7 ($4525.00) and GS-9 ($5440.00) levels, a few higher, depending upon qualifications of applicants.

Many of these jobs will offer career opportunities. Applicants are urged to write to the U. S. Weather Bureau, Personnel Division, Washington, D. C., stating qualifications and experience. Information will then be returned giving guidance on applying for appropriate Civil Service registers from which selections are made.

WEATHER BUREAU APPROPRIATIONS

"An Act making appropriations for the Department of Commerce and related agencies" for fiscal 1956 was passed in Congress as H. R. 6367 on 16 June and became law on 1 July.

The Act provides the Weather Bureau with an appropriation of $39.5 million for: (1) regular running expenses of the Bureau, (2) assuming responsibility for facilities formerly maintained by the military services, (3) the augmentation of a severe storm warning service and research program, and (4) the "establishment of facilities program" over the next four years.

A sum of $7.5 million was appropriated for the establishment of new facilities. Under this program approximately 86 upper-air stations will be furnished with modern rawinsonde equipment; 35 new-type, long-range radar sets will be installed to track hurricanes, tornadoes, and severe storms; about 90 major airports will be equipped with modern cloud height indicators and visibility observing equipment to facilitate bad weather landings. In addition, many of the points outlined in Rep. Patterson's "Hurricane Bill" (see *Weatherwise*, June 1955, p. 63) will be put into effect.

GUIDES TO THE LOCATION OF WEATHER RECORDS PRIOR TO 1870

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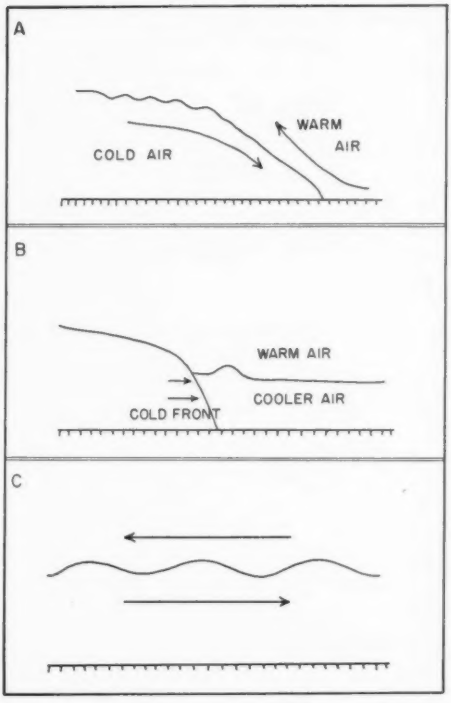
Waves in the Atmosphere

WILLIAM L. DONN, *Brooklyn College and Lamont Geological Observatory, Columbia University*

NEARLY everyone has seen waves on the surface of water, whether on the ocean, on lakes, rivers or ponds, or possibly only in the bathtub. Although the effects of these waves extend down below the water surface, the presence of a surface is a necessary condition for their formation, hence the name "surface waves." In addition to waves which develop on the boundary surface between water and air, oceanographers have recently reported that tremendous waves as great as 300 feet in height have been detected in the depths of the ocean; their surface of origin is that which exists between two water layers of different temperatures. Waves which form on a surface within a fluid are referred to as "internal waves" in distinction to those which form on the free surface of a fluid.



Three cross-sections showing conditions of wave generation within the atmosphere: A—waves forming on a cold front surface along the upper boundary of a wedge of cold air; B—a solitary wave on an inversion surface, with the wave generated by the pushing action of the cold front on the inversion; C—waves developed from wind shear between two moving layers of air.

Air is an even more mobile fluid than water, and we are coming to learn that nearly all of the types of waves in water have their counterparts in the atmosphere. The classical explanation for certain types of banded cloud forms considers them as originating in or being modified by internal waves high in the atmosphere. Recently a remarkable single, elongated cloud was photographed at Denver which had the appearance of a cross-section of the ocean extending from the beach out to deep water, for impressed on it were the contours of waves in various stages of formation. (See *Weatherwise*, April 1954.)

The presence of atmospheric waves, for the most part, is best shown on the continuous records of sensitive pressure and wind instruments. By analogy with liquids, it is well know that liquids of different densities in a container will separate into distinct layers, and that internal waves can be generated on the surfaces between these layers. In general, fluids of different properties tend to remain separated from each other when in contact. Thus the dense, turbid waters of the Missouri River, the "Big Muddy," flow downstream for many miles after joining the Mississippi, with a sharp discontinuity between their respective waters. Waves and eddies can be seen along this discontinuity. Similarly, air masses of different temperatures and densities moving through the atmosphere tend to retain their physical independence, being separated from each other by fairly sharp "frontal surfaces." These surfaces between air masses are ideal loci for the development of internal atmospheric waves.

Further, many meteorological factors often produce the condition of "inversion" in the atmosphere, in which a temperature stratification develops with higher temperatures pre-

vailing just above and lower temperatures just below this surface. Radiosonde data often reveal this. Inversions also provide the surfaces necessary for the generation of internal surface waves.

Another still more airy mechanism of wave generation seems to be associated with zones of wind shear developed from the presence of two layers having different directions or velocities of motion, or both. At the time of the unique Denver wave cloud mentioned earlier, there was considerable wind shear in the upper-air owing to the presence of the jet stream aloft, which had a 200-knot wind at its core.

The interval between successive ocean waves (wave period) breaking on a beach is usually 6 to 10 seconds. The periods of the more striking atmospheric waves are usually of much greater magnitude, from 4 to 25 minutes, although a fairly continuous spectrum of irregular atmospheric oscillations has been detected to as low as one-half second. However, these short-period fluctuations are usually related to local wind effects very close to the ground and are not considered to reflect any large-scale atmospheric problem.

The detection of atmospheric waves involves pressure and wind recording. Clearly, the passage of a wave through the atmosphere will change the total pressure value by only a very small fraction of this value. The familiar barograph is quite unable to detect pressure fluctuations associated with most atmospheric waves owing to its insensitivity and compressed time scale.

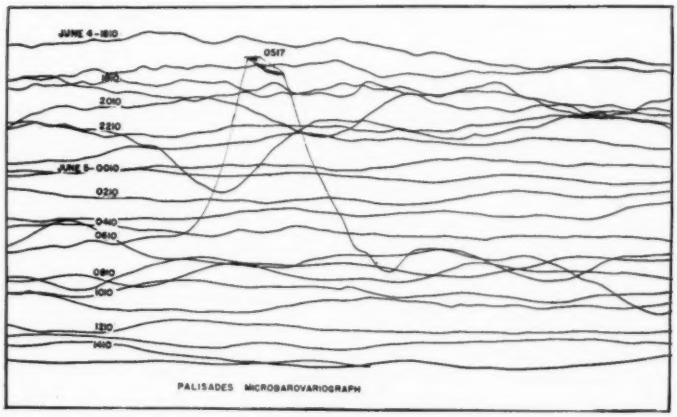
A simple instrument which overcame these deficiencies was developed at the Lamont Geological Observatory of Columbia University. In principle, two hollow glass flasks, one open to the air and the other sealed, are balanced at opposite ends of a rod which is centered on a knife-edge. Changes in atmospheric pressure upset the balance and cause motion of the flasks about the fulcrum. This motion is transmitted through an electrical amplification system to a photographic drum-recorder.

The results of the early study have proven very interesting. Waves resulting from the turbulent heating of the surface air become prominent following sunrise. These waves disappear at sunset, or when the sky becomes overcast. They have a period of the order of one-half to two minutes.

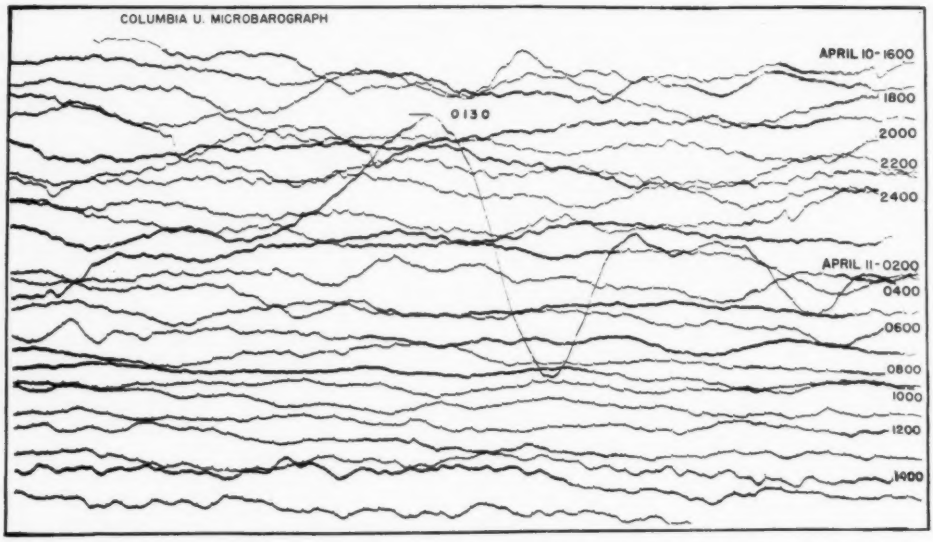
Very frequently, after a cold front has passed the station and moved some distance to the east, a train of very prominent and quite sinusoidal waves is recorded. They may be explained on the basis of waves generated on the upper frontal surface between the cold and warm air masses. Such waves commonly have a period of four to eight minutes.

Waves having the greatest amplitude of any yet noted accompany the "pressure jump." Since pressure jumps are now recognized as having important associations with tornadoes and may be closely related to the origin of such violent phenomena, a special study of this feature is in progress.

A further important application of this technique has been the study of the details of pres-



A pressure record of 4–5 June 1953 on the Palisades microbarovariograph shows a very striking solitary wave about 0500 GMT. This pressure variation was attributed to a wave traveling on an inversion surface aloft.



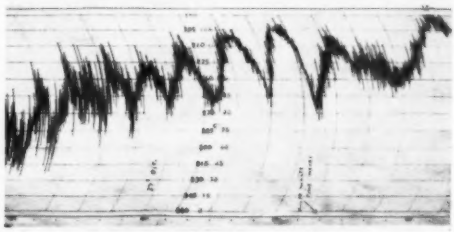
A prominent wave was recorded on the Columbia University microbarovariograph at 0130 GMT on 11 April 1953. It was attributed to the passage of a single thunderstorm cell. The period of the wave was about 20 minutes.

sure variations accompanying isolated thunderstorms. Atmospheric fluctuations related to many local air mass thunderstorms appear to indicate a simple cell consisting of two downdrafts with an intervening updraft. From the period of the pressure oscillations on the record and a knowledge of the velocity of the storm, many of the dimensions of the cell can be determined. These dimensions often agree very well with those given by the Benard convection model. Here, too, is an area in which much further study will be made.

To be quite scientific, one must admit that pressure data alone do not conclusively prove wave motion in the atmosphere. However, the study of wind motion gives the necessary conclusive support. Consider the ocean again. It is common knowledge that as a wave moves through the water, a particular water particle describes a circular orbit as the wave passes. Depending on depth, this motion may reach the bottom of the ocean. At the bottom, however, a water particle simply describes a linear "to-and-fro" motion in the direction of propagation of the wave, because the ocean floor inhibits the vertical movement necessary to complete the circular course.

Now the air at the ground beneath an internal surface wave should also show this to-and-fro motion. If no surface wind were present, the air motion at the ground would show a periodic reversal in direction as a group of waves passed aloft. If surface wind were to exist, the effect of wave passage in the air would be to impose a periodic variation on the velocity and direction of the observed wind. The magnitude of these variations would depend on the size and velocity of the waves and the velocity and direction of the wind at the ground. These deduced ef-

(*Continued on page 106*)



Wind direction recordings at Brookhaven National Laboratory, Long Island, demonstrate periodic variations of about 80 degrees over a wave period of about 22 minutes. Unidentified atmospheric waves caused the variations.

A cloud of twinkling ice crystals falls toward the bottom of the cold chamber. Photo by the author.

Simple Experiments in Atmospheric Physics—3

Methods of Forming Ice Crystals in a Supercooled Cloud

VINCENT J. SCHAEFER, *Director of Research, The Munitalp Foundation, Inc.*

ICE crystals may be formed in many ways in a supercooled cloud. In fact they may actually be formed in cold, cloud-free air under special conditions. There are two basic phenomena controlling such formations.

One involves the generation of crystals in pure air without the need of nuclei of any kind. The other depends completely on the presence of certain specific types of floating particles. I will first describe some of the techniques for initiating crystal formation in air free of ice nuclei. For convenience, the methods described may be carried out in an ordinary chest-type cold chamber, cooled to − 10° to − 20° C, whose top is open to the surrounding air.* Under most cases this air will be relatively free of ice crystal nuclei. If some are present and crystals form on them, they should quickly snow out soon after a supercooled cloud is formed.

Even if a few ice crystals are present in the cloud, the methods which will be described produce such tremendous numbers of new crystals that the effects will overshadow any natural concentrations which may occur.

THE FORMATION OF CRYSTALS USING DRY ICE

A simple method for creating crystals with dry ice has already been described. A supercooled cloud is formed by exhaling a few lungfuls of air into the chamber, or by waving a damp cloth in the cold air, or by injecting moist air from a "nebulizer" or other moisture

* See *Weatherwise*, April 1955.

source. The dry ice may be introduced in several ways. Perhaps the most spectacular effect is obtained by holding a chunk of dry ice with a glove a foot or more above the supercooled cloud in the chamber. If the cloud is relatively quiet and the dry ice is suddenly scratched with the sharp edge of a small screw driver, needle, or similar tool, a shower of white condensation trails suddenly appears in the cloud and within a few seconds the entire chamber is filled with twinkling crystals. In this simple operation it is feasible to produce 100 million ice crystals! This number may be increased ten thousand times by blowing moist air over the surface of a piece of dry ice. So many crystals form that the resultant cloud appears blue when illuminated by a parallel beam of light, and the crystals are so tiny and numerous that much moisture must be added to the cloud before the crystals grow large enough to be recognized by their twinkling appearance.

Other variations of the dry ice method may be used, including tying a small chunk to a piece of string and passing it horizontally across the top layer of the supercooled cloud; holding a piece stationary above the cloud so that the air streaming over it cascades down into the cloud; placing a chunk in a container of water, alcohol or other liquid so that the evolved cold carbon dioxide gas comes in contact with the water droplet cloud.

It is not necessary to use chunks of dry ice to produce ice crystals. Liquid carbon dioxide may be used. A convenient source is the small pressure capsules used for carbonating water or driving model airplane engines. A tiny needle valve may be obtained at the model airplane shop for piercing the capsule and delivering controlled amounts to the chamber. As the gas is released, it expands and cools to a temperature of $-78.5°$ C, thus producing tiny bits of carbon dioxide snow. A "blue" cloud of crystals is easily produced by opening the valve momentarily.

Ice Crystals Produced by Liquid Nitrogen

There is nothing peculiar about dry ice in generating ice crystal formation except its very cold temperature. This may be indicated by using another cold source such as liquid nitrogen. This substance, common to all physical research laboratories, has a temperature of $-195.8°$ C. A few tiny drops of the liquid spattered into the supercooled cloud or some of the chilled gas poured from the mouth of the Dewar flask used for holding the liquid will produce ice crystals in exactly the same manner as with dry ice in solid or liquid form.

Perhaps the most convincing evidence that cold alone is required can be demonstrated by taking a needle, a small wire, or any solid object. If suspended in the liquid nitrogen for a few seconds and then passed briefly through a supercooled cloud, myriads of ice crystals will form in the wake of the cold object. The same effect may be produced by cooling the solid object with dry ice.

A simple experiment demonstrates this "cold" effect. If a thermometer is available which will register a temperature of $-40°$ C, progressively cool it toward that temperature. This may be done by putting it in a cavity between a few chunks of dry ice. From time to time as the thermomenter cools toward $-40°$ C, it is removed from the cooling cavity and passed briefly through a supercooled cloud. Careful observation in the wake of the thermometer will show a few crystals will appear in this region when the thermometer registers a temperature colder than the supercooled cloud. The number of these particles remains small as the thermometer is successively cooled to -20, -25, -30, -35, $-38°$ C. Suddenly, however, in the range of $-38°$ to $-40°$ C, myriads of ice crystals suddenly appear. A detailed study has indicated that spontaneous ice crystal nucleation occurs at a temperature close to $-39°$ C.

The Formation of Ice Crystals by the Sudden Cooling of Air

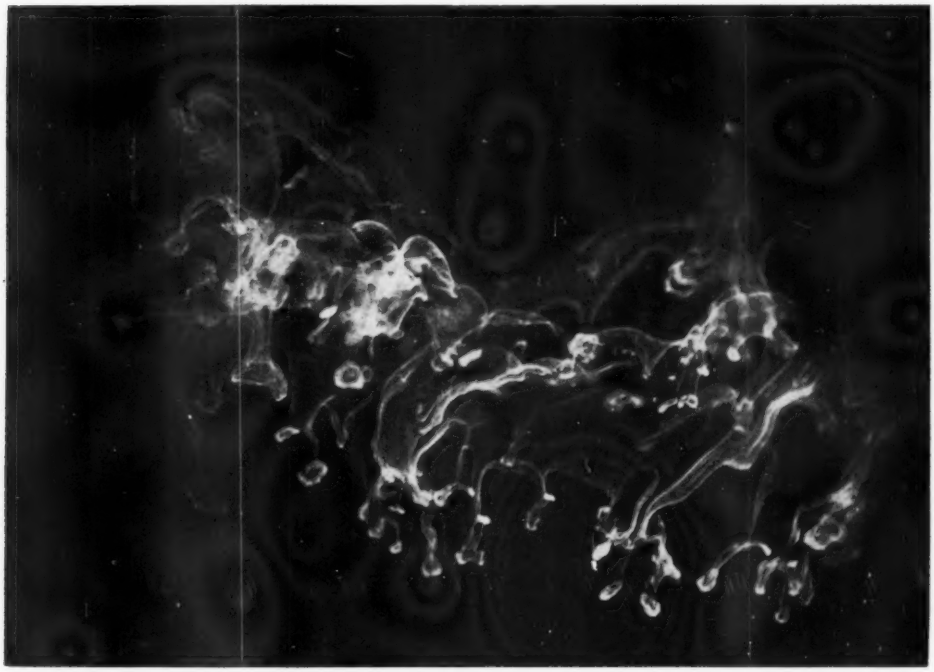
Since ice crystals form spontaneously in moist air colder than $-39°$ C, it might be expected that any method which produces this degree of cooling will produce large numbers of ice crystals. This may be demonstrated in a number of simple experiments. A simple

pop gun may be used to generate ice crystals in a concentration of one billion per cubic centimeter! (A cubic centimeter is a cube with sides slightly longer than $\frac{3}{8}''$.) A bicycle pump may be converted to a pop gun by removing the end opposite the moveable pump handle and replacing it with a cork or rubber stopper. To produce ice crystals with this simple device, one merely makes a short stroke with the pump to compress the air, holds it for a few seconds to allow the air to cool, and then with a further push causes the cork to pop out. A blue cloud of ice crystals will quickly permeate all parts of the supercooled cloud. The sudden expansion of air causes adiabatic cooling to temperatures colder than $-40°$ C and thus generates crystals in fantastic concentrations. Careful laboratory studies, using a miniature refined pop gun and breaking tiny glass spheres containing pressurized air, show that at least 20 billion crystals per cubic centimeter may be formed in this simple manner.

Many similar methods will produce the same effect. Moist air emerging from a high pressure air line (90 pounds per square inch), air from vortices in wing and propeller tips of aircraft, air from the cold side of a Ranque-Hilsch tube, or simply moist air introduced into a cold chamber, or the outdoor air when the temperature is colder than $-40°$ C will produce this effect.

Condensation trails from high flying aircraft and the ice fog hovering over herds of muskox or caribou in polar regions are good examples of spontaneous ice crystal formation when water vapor condenses at temperatures colder than this critical value.

One additional process of forming pure ice crystals at temperatures warmer than $-39°$ C will be described in a later article under the term "fragmentation nuclei."



Submicroscopic ice crystals formed by passing a small piece of dry ice through a supercooled cloud. Photo by the author.

Weatherwatch

Late Spring Favors the Farmers

DAVID M. LUDLUM, *Editor*

For the first time in five years the writing of the weather news of the middle and late spring is a pleasure to perform. With the exception of one major tornado tragedy, the weather elements were rather well behaved. The specter of drought in the southern Plains was definitely allayed in May; for the first time in four years agricultural interests there could look forward confidently to a season of summer crops. Elsewhere in the country the moist weather of June and the late June–early July heat wave brought crops along in fine style. At the close of June agricultural prospects were described as good to excellent, and predictions were that the quantity would be second only to the bumper year of 1951.

It is interesting to point out to prophets of drastic climate change that the upturn in the agricultural behavior of meteorological conditions coincided with the releasing of much nuclear energy in the Nevada deserts. It was only two years ago that certain parties were claiming that the nuclear tests were causing the great droughts in the same areas that the recent rains have favored. As a matter of fact, the frequency of tornadoes during early 1955 has been less than in some previous years when no nuclear tests were held. With the evidence at hand it is the opinion of the writer that nature takes little cognizance of man's puny explosions when dealing out droughts and floods, tornadoes and calms, heat spells and cold waves.

MAY—The principal feature of the circulation pattern for May 1955 was the strengthening of a block in the westerlies that had developed in the previous month. With the flow of the elements eastward across the continent diverted from a normal path, the country was divided into two temperature compartments: cool in the West and warm in the East.

Ridge conditions prevailed from southern Greenland southwestward to the Gulf of Mexico, with the main positive pressure departure from normal centered over southern Baffin Land. This long ridge afforded an effective path for warm southwesterly winds to traverse the central valleys and Lakes region and to reach the sub-Arctic in Canada, bringing a forward spring to most of the vast interior of the continent.

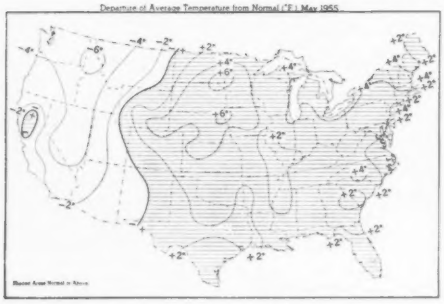
Upstream from the blocking high over eastern North America, pressure was below normal over all of the Canadian Northwest and Alaska with a distinct trough in evidence trailing southward from British Columbia to southern California. The lower end of this trough favored cyclogenesis throughout the month, and it is here that the main weather news of the month developed.

The western trough was responsible for the movement of cool Pacific air into the Pacific and Plateau states to continue the below normal weather regime of the past months there. The Pacific High was strong and in conjunction with a deep Aleutian low brought a fast sweep of westerlies across the eastern Pacific and into the continent. The Pacific air, always cool at this season, caused freezes and frosts in the Pacific valleys as late as early June.

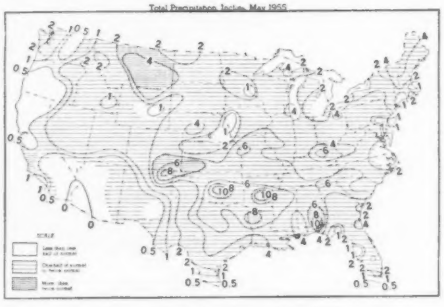
East of the Great Divide, however, it was a warm May and very favorable for field work in the agricultural areas. Air flow east of the Rockies was from the southwest throughout the month as an upper level anticyclone hovered over the central Gulf of Mexico to stimulate the flow of warm, tropical air from Mexico to the Arctic. Temperature readings in the Hudson Bay area were often well above those reported in Oregon and Washington.

The southern end of the western trough over southern California was a breeder of cyclonic disturbances which moved eastward until caught up in the great southwesterly flow and rushed northeastward to central Canada. Another cyclonic track of the month came from the Aleutian

MONTH OF MAY 1955



Departure of Mean Temperature from Normal in degrees F. USWB chart.



Total Precipitation in inches. USWB chart.

low where North Pacific disturbances moved across central and northern Canada, again stimulating a southerly flow to the sub-Arctic and beyond.

In the East the mean ridge line for the month extended along the crest of the Appalachians. The next trough downstream was well offshore, from a point south of Greenland to central Cuba with a southwesterly orientation. The northwesterly flow along the immediate coast was moderately warm and rather dry. Since the main storm track in the trough was too far offshore for the canopy of precipitation to reach westward to the coast, many points in the Middle Atlantic states complained of drought and resort was made to irrigation in the threatened area.

JUNE—A study of the temperature and precipitation maps of May and June indicates that a major change in circulation took place between the two periods. The low pressure system which originated in the far Southwest about 23 May drifted very slowly eastward during the closing days of the month to give Eastern forecasters much Memorial Day trouble. It finally reached the Atlantic Coast on 30 May where it merged with a deepening trough which was to be a principal feature of the June circulation. The main tendency of the mean ridges and troughs in May–June was to shift slowly eastward. The minus pressure departure from normal, so prominent over the far Southwest in mid-May, moved to the region of the Missouri Valley by late May and remained a recognizable feature throughout the following month. Meantime, the Atlantic trough developed, and during the last two weeks of June pressure was much below normal over the Carolinas-Virginia coastal area, an unusual occurrence for this time of year.

During these shifts, however, the main feature of the May map, the anticyclonic activity over northeastern Canada, persisted and strengthened its blocking effect in June. The southern part of the ridge over the United States faded away as an important blocking feature with the result that a spit in the westerly flow became noticeable; a low latitude jet moved across southern United States from the Pacific while the northern branch was in Canada. Cyclonic and frontal activity were frequent along the path of the southerly jet, causing much cloudiness, rainfall, and cool air over central portions of the United States.

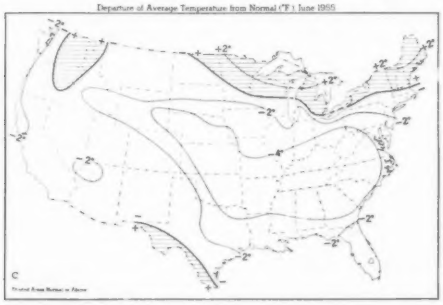
The area from the Rockies eastward, so warm in May, was now much below normal in mercury readings as the flow of southwesterly air was shut off and Canadian air moved southward. The entire country, with the exception of the Rio Grande Valley and a shallow section along the northern border, experienced below normal readings in June. Ridge conditions along the Pacific Coast permitted a warm spell with high daytime maxima early in the month, but radiation was active and nighttime minima were low, so averages were close to normal.

The weather elements, however, are never in a state of repose—the last days of June witnessed another major change in circulation. On 23 June a large high pressure area appeared over northwestern Canada, and by the 24th had pushed its front of cold air all the way to the Ohio Valley with delightful clear skies, moderate temperatures, and low humidities. The front between the polar and tropical air masses remained in the Southeast for four days. By the 29th the center of the high pressure had drifted southeastward to the coast and joined with the Bermuda High. Meantime, the polar air mass had heated up in its slow drift and the stage was now set for the return circulation of modified polar, then tropical air. Day by day the air became hotter and hotter. Most of the country east of the Rockies experienced an intense early July heat wave that reached a climax on the Fourth of July with 100° readings reported at scattered points from Kansas to New England. Resort concessionaries and farmers, alike, welcomed the heat as relief from the June regime of cloudy skies and rain.

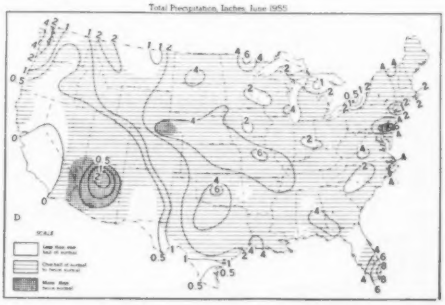
ANOTHER TORNADO TRAGEDY—On the afternoon of 25 May a tornado situation developed over north-central Oklahoma, forecasters went on the alert, and soon issued warnings to the general public. During the evening hours at least 15 tornadoes were reported over a 200 square mile area that lay within the bounds of the warned section. Over 100 persons were killed, 300 hospitalized, and damage in the millions occurred.

The synoptic situation accompanying these tornadoes will probably become a classic example for severe storm students. According to currently accepted theory, the main ingredients of a tornado situation in the southern Plains are: warm, moist air with dew points near 70° in a strong southerly flow, cold polar air to the northward, and dry Pacific air overhead with a fast jet-like flow. All of these appear to have been present in the area

MONTH OF JUNE 1955



Departure of Mean Temperature from Normal in degrees F. USWB chart.



Total Precipitation in inches. USWB chart.

north of Oklahoma City to Wichita, Kansas, on the afternoon of the 25th.

A warm front extended from the panhandle sector of west Oklahoma east-northeastward to near Wichita; surface winds were southeast in most of this sector; dew points were in the high 60s and the afternoon maximum temperature had reached 87° at Wichita; much cooler and drier air with dew points in the 50s occupied the western parts of Kansas, Oklahoma, and Texas. The upper-air pattern showed a strong flow of south-southwest winds at 20,000 feet over the tornado area with a shift to northwest about 250 miles westward at the upper-air trough line.

The major tornado originated near Tonkawa, Oklahoma, 80 miles north of Oklahoma City, soon after 2100 CST. It struck a section of Blackwell, killing 20 persons, and then roared up tornado alley with an apparent skipping motion. An aerial survey showed no damage at Braman, but considerable farm damage in the vicinity of the Oklahoma-Kansas border. There was no damage at Oxford, but at 2330 the twister erased the community of Udall (population 600), 25 miles southeast of Wichita. Every home was demolished, every public or business building was damaged so severely as to need replacement, every automobile in the community was put out of service. In a few short minutes of fury 80 lives were snuffed out and over 200 seriously injured. During the next few days bulldozers cleared away what had been the habitations of 600 persons; a temporary city hall was erected; and plans were formulated for rebuilding the community.

There have probably been few tornadoes that have been better anticipated, better forecasted, better watched by radar, and the public kept better informed than in the Blackwell-Udall tragedy. The thunderstorm activity with severe turbulence was constantly under the surveillance of the Wichita radar from 2145 to 0005 on the 26th. Microphones at the radar relayed the latest observations to the public. Yet great loss of life occurred, nevertheless.

WEATHER & CROPS—At the end of the first week of May the moisture situation in the crop areas was described: "Rain is now badly needed in most of the South Atlantic and Gulf states where little has fallen during the past 3 weeks, and moisture is becoming increasingly deficient northward over the Ohio Valley. Conditions are the most serious in the Great Plains where many sections as far north as central North Dakota report some soil erosion during the week. The drought, that persists in the middle and lower sections of the Western Plains, is now spreading eastward and northward over the Great Plains."

The drought in the southern Plains and in the far Southwest has been a feature of the news ever since 1950, and it became a major national concern in 1952. A recent survey of precipitation records back to 1890 does not show any other three consecutive years with such a continuing deficiency as 1952–1954. During May and June, however, general rains fell over the erstwhile parched area, and there are indications that the drought may have been broken. It will take many months to be certain that the change to a more moist regime is real.

The upper-air low pressure trough that hovered over the Southwest during May nurtured a number of depressions. As they moved slowly eastward, they drew on far-off moisture sources. From a study of upper-air winds it appears that the moisture for the initial Dust Bowl rains came from the Pacific Ocean. General rains fell on west Texas on 9–10 May and again on the 17–20th. The latter rains were shared by Colorado where other showers fell on the 22–23rd and 24–25th. Kansas had especially heavy falls on the 25–27th. The rains showed a tendency to work constantly northward and reached the northern Plains during the last week of May.

Some unusual amounts were recorded in New Mexico and Colorado. At Lake Maloya in New Mexico 11.28 inches fell in 48 hours on the 18–19th. At Black Lake nearby 22 inches of wet snow fell. Rye, in adjacent Colorado, had a catch of 6.10 inches on the 18th and a total for May of 11.74 inches. As usual these cloudbursts brought on flash flood conditions, and the Arkansas River went on a rampage, the first since 1951.

Soil moisture conditions at the beginning of June were adequate in all former drought areas and the general crop outlook was "good to excellent." Though the winter wheat in northwest Texas was a complete loss and about one-third of the crop was abandoned in Oklahoma, the grass lands revived and the western Plains had the best prospects for row crops since 1950. In speaking of the rains of mid-May, the weatherman at Amarillo said: "The transformation from drought to green pastures is wonderful to behold."

HONORARY DEGREE

Ivan R. Tannehill, former assistant chief of the Weather Bureau, was one of three graduates of Denison University who received honorary degrees at its 122nd annual commencement in Granville, Ohio, on 13 June 1955. Mr. Tannehill, Class of 1912, was awarded the honorary degree of Doctor of Science. Mr. Tannehill, who retired from the Weather Bureau on 31 October 1954, lives at 4635 Warren Street, N.W.

Waves in the Atmosphere

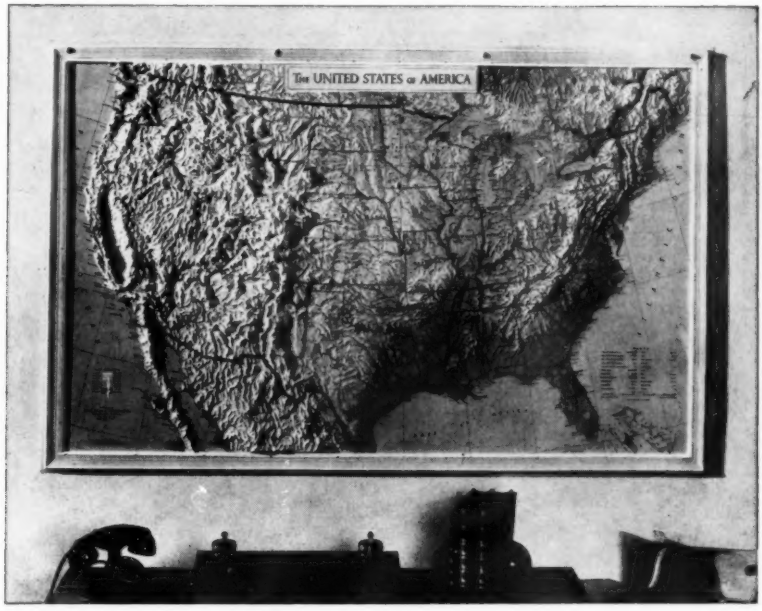
(*Continued from page 100*)

fects have been observed, as shown in the illustrations.

Another method for solving the direction and velocity of atmospheric waves consists in setting up a triangular array of sensitive pressure recorders many miles apart. The difference in arrival times of the waves at each instrument is then converted into values for direction and velocity. Speeds of 20 to 100 mph have so far been noted. Much more research will be devoted to this subject.

In addition to the above phenomena, many other wave-like fluctuations of the atmosphere have been observed, the origin and meaning of which are still very uncertain.

Aero Plastic Relief Maps



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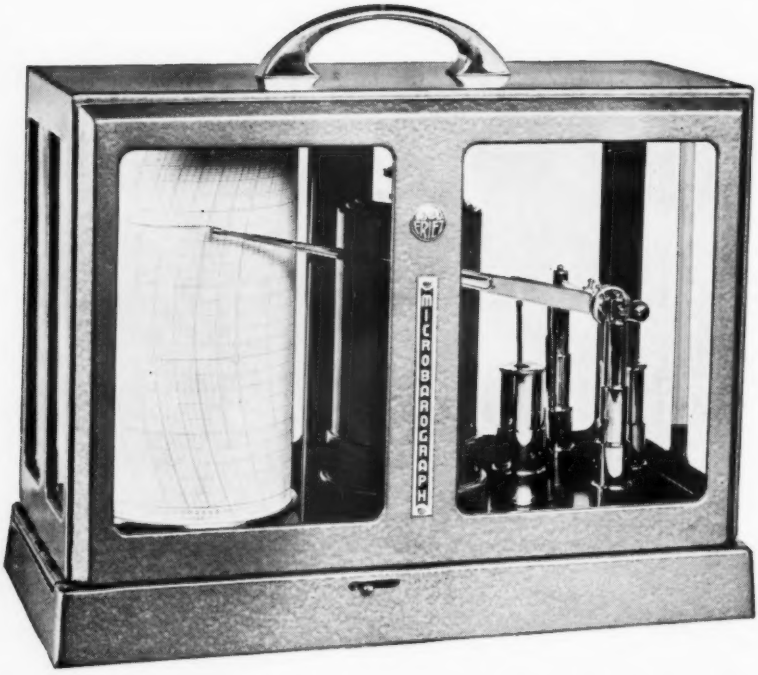

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